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Abstract

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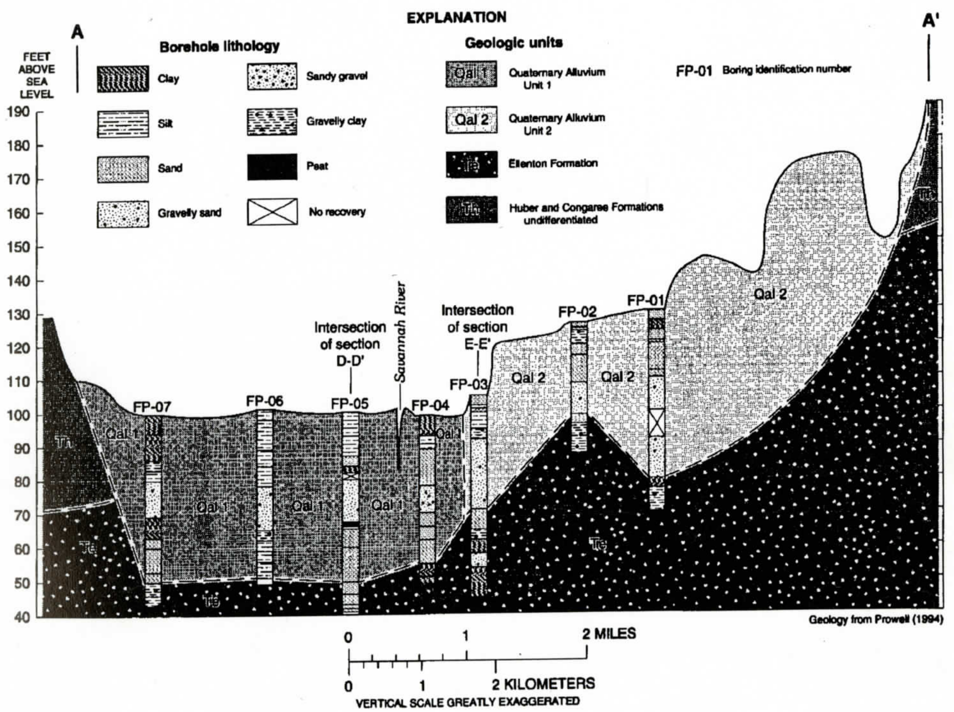
SOUTHEASTERN GEOLOGY



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2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
3) Submit line drawings and complex tables reduced to final publication size (no bigger than 8 x 5 3/8 inches).
4) Make certain that all photographs are sharp, clear, and of good contrast.
5) Stratigraphic terminology should abide by the North American Stratigraphic Code (American Association Petroleum Geologists Bulletin, v. 67, p. 841-875).

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EDITOR'S PAGE

Number Two

In the first Editor's Page I announced plans to put a searchable index of all 600 plus titles and authors on the Southeastern Geology home page on the World Wide Web. The index is up and working. The Web address is:

http://www.geo.duke.edu/seglgy.htm

A project for the near future is to put the preferred formatting instructions for accepted manuscripts on the Web. Look for other information about the journal on the Web.

This issue contains another article related to the Savannah River Site. This is the fifth article published since October 1992 on some aspect of SRS. As many readers know, SRS, like all of the early atomic bomb sites, is severely polluted. In addition it is a temporary storage site for high level waste. It is important to know all that we can of the structure, stratigraphy and hydrology of this area. We are proud that Southeastern Geology has been able to publish these data about SRS.

This issue contains an article on the history of geology in West Virginia. It is the second history article within the pages of this journal. The other one was published in the December 1981 issue. Southeastern Geology is not a history of geology journal, but a little knowledge of those that went before us and their contribution to the geology of our region helps us to appreciate the shoulders that we stand upon.

If you are preparing a manuscript on any phase of the geology, hydrology or environmental geology of the southeast, I encourage you to submit it to this journal. The manuscript will be given a fair review by two peer critical readers as promptly as possible.

Duncan Heron

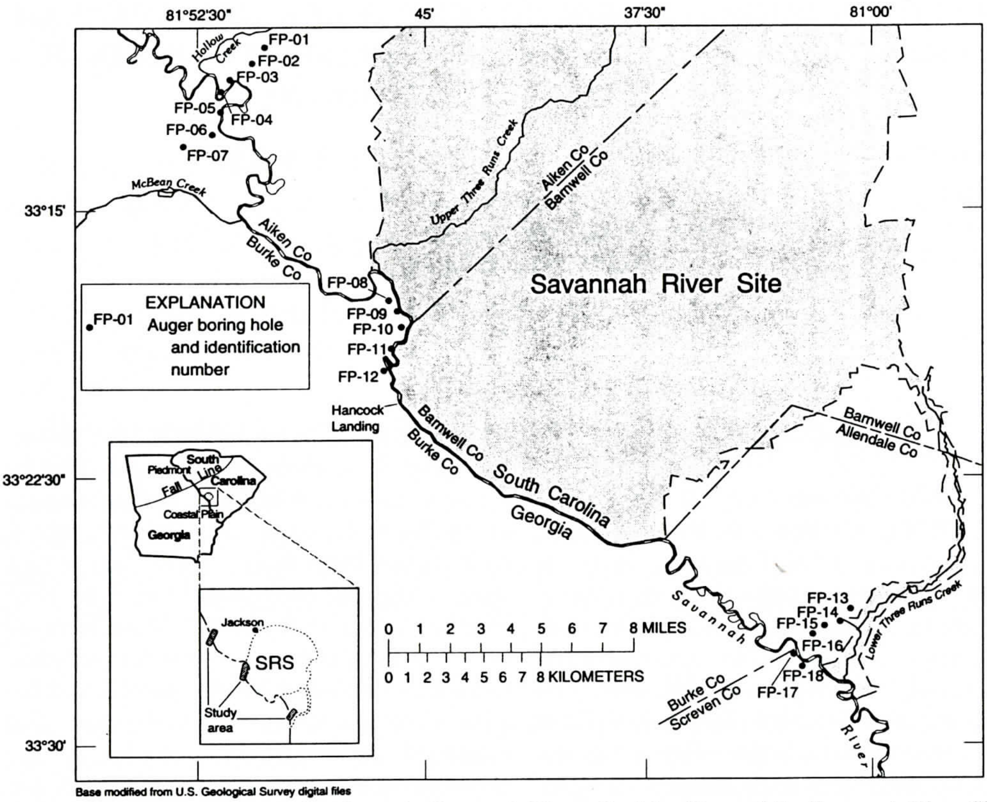


Figure 1. Location of auger holes along the Savannah River alluvial valley and the Savannah River Site in Georgia and South Carolina.

his conclusions.

In 1991, the U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, began a cooperative study to evaluate if flow conditions existed that would allow ground water from South Carolina to flow beneath the Savannah River into Georgia (trans-river flow) (Figure 1). As a part of the Savannah River Site (SRS) study, three drill-hole transects and two electromagnetic conductivity transects were completed across the Savannah River alluvial valley in September 1993. This paper examines the geologic and stratigraphic data from these transects to determine the depth, thickness, and character of the alluvial valley fill, and makes some inferences concerning the fluvial history of the river valley.

The study area for this paper is adjacent to the SRS and lies wholly within the upper Coastal Plain physiographic province (Figure 1). The area includes the alluvial valley of the Savannah River from just south of Hollow Creek to immediately north of Lower Three Runs Creek (Figure 1), a distance of about 25 miles. The study area lies about 180 ft. above sea level in the northwest to about 70 ft. above sea level in the southwest, and is the westernmost boundary of the Aiken Plateau (Cooke, 1936, Colquhoun and Johnson, 1968). In Georgia, Clark and Zisa (1976) delineate the area as being in the Fall Line Hills District to the north and the Vidalia Upland District to the south.

Previous Studies

Previous investigations of the region surrounding the Savannah River are numerous. Recent studies include summaries of local geology and hydrology by Pollard and Vorhis (1980), Colquhoun (1981), Faye and Prowell (1982), Prowell and others (1985a, 1985b),

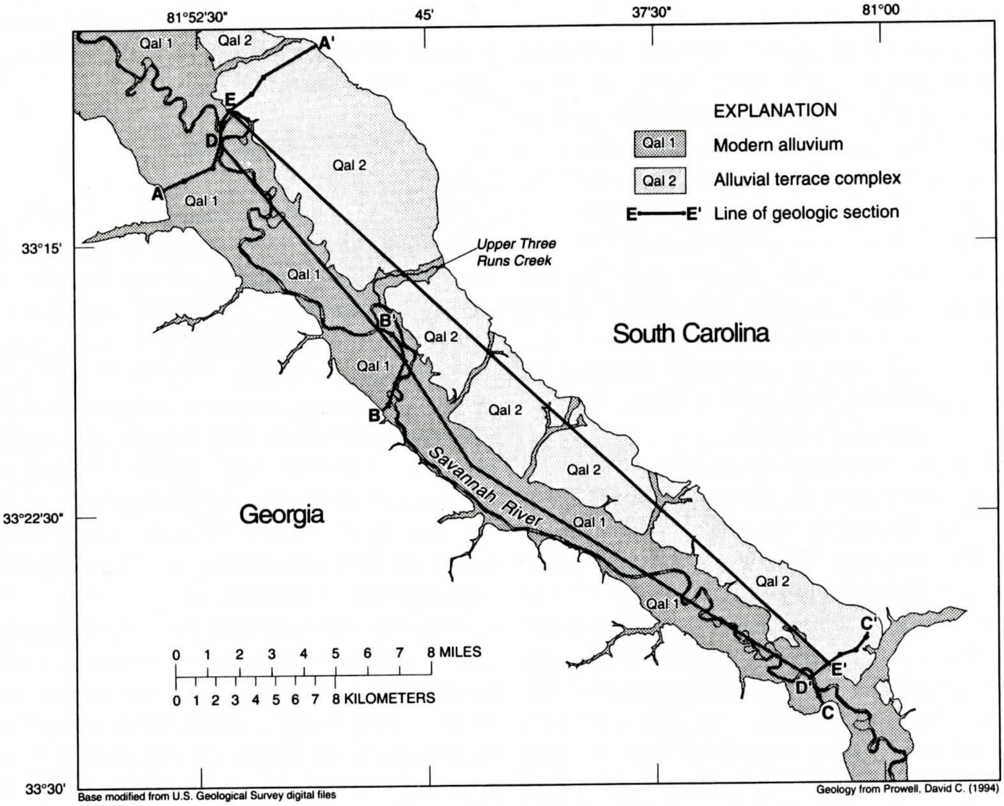


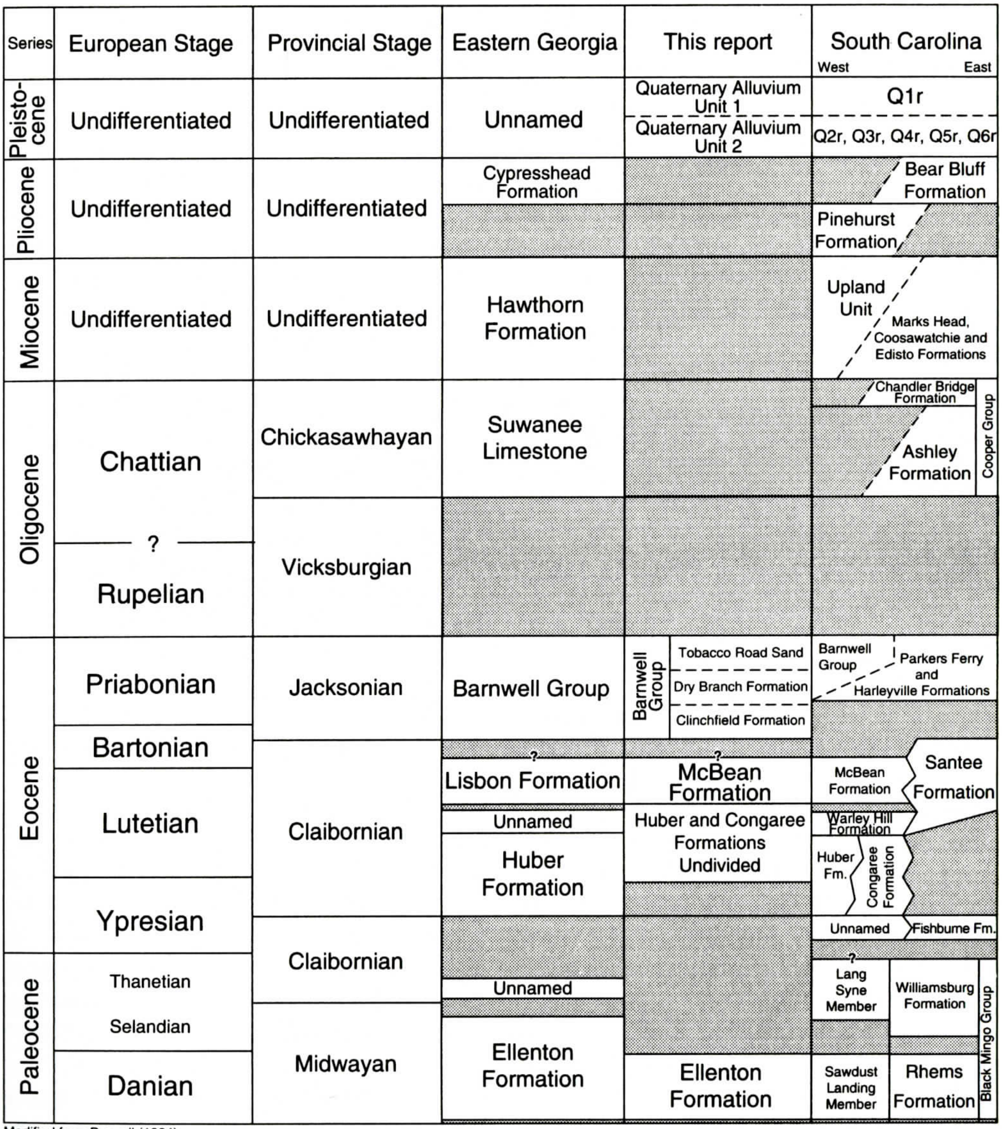
Figure 2. Location of geologic sections and Quaternary geologic units.

geologic materials. In this paper, the initial hypothesis was that such a contrast could be apparent between the unconsolidated alluvium and underlying, partially consolidated, and more compact formation.

GEOLOGY

The central Savannah River alluvial valley is underlain by Cretaceous, Tertiary and Quaternary age strata that increase from a minimum thickness of about 380 ft. at the northwestern end of the study area to 1,480 ft. in the southeastern end near Lower Three Runs Creek (Wait and Davis, 1986). The floodplain covers the modern-day alluvial bottom and alluvial terrace complex mapped by Prowell (1994) as Quaternary Alluvium 1 (Qal 1) and 2 (Qal 2) (Figure 2). Stratigraphic names, used in this paper, are based on map units defined by Prowell (1994) and paleontological data from nearby cored wells (Edwards, 1986). A correlation chart of geologic units is shown in Figure 3. The term bedrock is used to describe the partially consolidated to unconsolidated sediments older than Pleistocene.

The Ellenton Formation of Paleocene age underlies the alluvium of the northern transect (A-A', Figure 2). The Paleocene age of the Ellenton is consistent with the earlier works of Prowell and others (1985b) and Edwards (U.S. Geological Survey, oral communication, sample R-3725, 1986). In borings FP-01 through FP-07, the Ellenton is consistent with the description by Prowell and others (1985b) as a moderately to well sorted; fine to coarse; subangular to subrounded quartz sand in a buff to light-gray clay matrix with small quantities of very fine, dark, heavy minerals; and white mica. Several borings of the northwestern transect encountered stiff to very stiff, gray, red



Modified from Prowell (1994)

Figure 3. Correlation chart of geologic units.

and orange kaolintic clay layers not mentioned in previous investigations. In this transect, the Ellenton can be most readily differentiated from the alluvium by this clay; however, the presence of a white kaolintic rime on individual clasts is also indicative of the Ellenton Formation.

The alluvium of the middle transect (B-B', Figure 2) is underlain by the McBean Formation and the undivided Huber and Congaree Formations of Middle Eocene Age (Lucy E. Edwards, U.S. Geological Survey, written communication, 1994 samples R4836 L and R4836 M). In borings FP-08 through FP-12, these formations are typically a dark green, compact, fine to coarse grained, moderately to well sorted, subrounded to rounded, quartz sand with intermittent, stiff clay; and are differentiated from the overlying alluvium by differences in color, less angularity and better poorly understood because absolute and correlative ages are widely divergent. Qal 1 radiocarbon data are limited to eight samples; one reported by Geomatrix (1993) and seven reported by Stevenson (1982). Geomatrix reports an age of 130 ± 50 years before present (B.P.) for a shallow (3.5 ft.) Qal 1 sample. Of the seven Qal 1 samples reported by Stevenson (1982), the youngest was collected at a depth of 3.2 ft. and assigned an age of 245 ± 85 years B.P. The oldest sample was collected at a depth of 10.5 ft. and dated at 4,010 ± 130 years B.P.

Datable material has not been collected for Qal 2, but age estimates range from 10,000 to 350,000 years B.P. Brooks and Colquhoun (1991) used artifactual data to conclude that the youngest age of Qal 2 material is approximately 10,000 years B.P. The 10,000-years B.P. is in marked contrast to the 200,000- to 350,000-years B.P. age reported by Hanson and Bullard (1992) who estimated ages from soil-profile characteristics.

Nystrom (1992) reports four middle-Wisconsian and one late-Wisconsian radiocarbon age from Upper Three Runs and its tributaries on the east side of the Savannah River valley (Figure 2). The middle Wisconsian ages ranged from 33,900 years B.P. to greater than 46,000 years B.P.; whereas, the single late Wisconsian age was reported as 11,110 years B.P. The middle Wisconsian ages carry the most uncertainty because they are near the extreme range of application for carbon-14 dating.

No attempt has been made to correlate the alluvium with current regional stratigraphic nomenclature because of the extreme age differences reported by authors and the sparsity of data concerning the age of alluvium in the area of study. This type of correlation would rely solely on the morphology and/or height of the terraces referenced to some arbitrary base level, and the assumption of a relatively uniform climatic, eustatic, and tectonic system that is regional in scope. As Soller (1988) points out, these "historically persistent assumptions that a specific terrace is uniformly uplifted and everywhere the same elevation is too generalized and has led to miscorrelation of transgressive-regressive sequences along the Coastal Plain".

DRILLING TRANSECTS

The northernmost transect (Figure 2) is represented by geologic section A-A' (Figure 4). Qal 2 was fully penetrated by borings FP-01, FP-02, and FP-03 and reached a maximum thickness of 50 ft. in boring FP-01and a minimum thickness of 34 ft. in boring FP-03. Qal 1 sediments were fully penetrated in this transect by borings FP-04 through FP-07. Borings FP-05 and FP-07 encountered the underlying Ellenton Formation 50 ft. below land surface at the maximum incision elevation of 50 ft. The minimum thickness of Qal 1, 43 ft., was observed in boring FP-06.

The middle transect (Figure 2, B-B') provides data on both the transverse and parallel variation of Qal 1 near Hancock Landing, Ga. (Figure 5). The lowest incision elevation defined by this transect occurred in boring FP-10 where the river incised to an elevation of 45 ft. The maximum thickness of Qal 1 occurred in boring FP-10, where the stratum was 45 ft. thick; whereas, the minimum thickness of 22 ft. was encountered in FP-08. This difference of 23 ft. between the maximum and minimum values is attributed to the fact that FP-08 was drilled into the sideslope of the bedrock strath.

The southern transect, near Lower Three Runs Creek, S.C., (Figure 2, C-C') consisted of the remaining six borings (Figure 6). In this transect, Qal 1 has a thickness of 34 ft. in boring FP-17 and reached a maximum incision elevation of 42 ft. Qal 1 was not encountered in boring FP-18 (Figure 6). For borings located in Qal 2 material, the highest incision elevation occurred at boring FP-14 where the river reached an elevation of 80 ft. (Figure 6); and the lowest elevation occurred at boring FP-16 where the lowest incision elevation was 57 ft.

Selected borings from the three transects (Figure 2, A-A', B-B', C-C') were used to create downstream geologic sections (D-D' and E-E'; Figures 7, 8) of the two terraces. These sec-

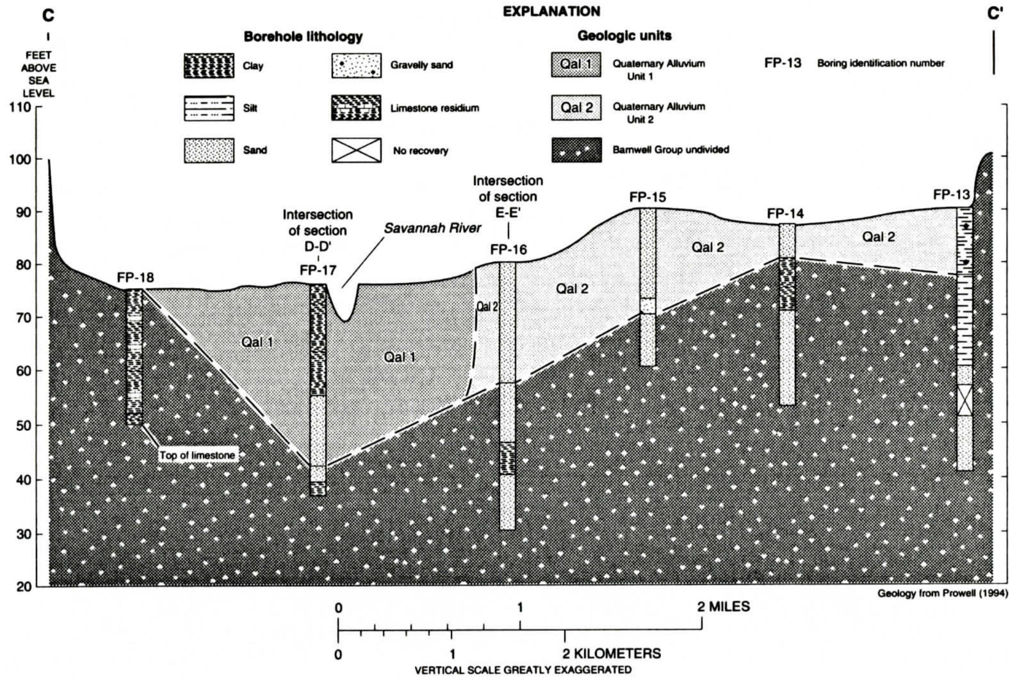


Figure 6. Geologic section C-C' showing lithology and depth of alluvium near Lower Three Runs Creek, South Carolina.

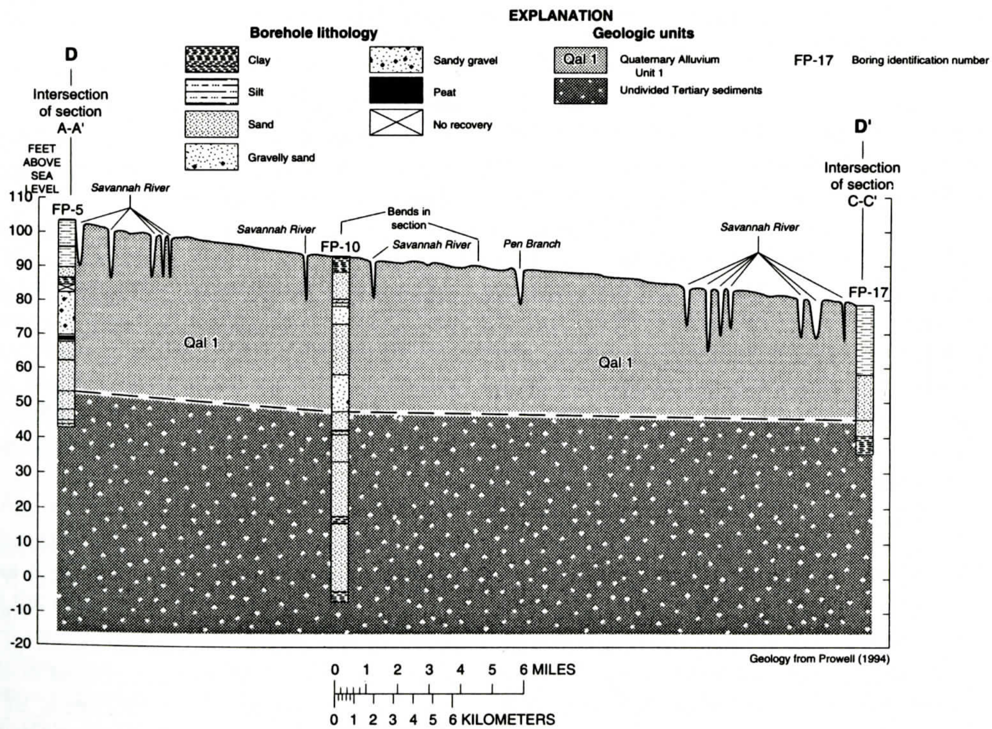


Figure 7. Geologic section D-D' showing lithology and depth of Qal 1 from near Jackson, South Carolina to Lower Three Runs Creek, South Carolina.

(1993), that near the SRS, the maximum incision of the ancestral Savannah River into the Tertiary Coastal Plain formations was approximately 50 ft. These data also show that the elevation of the basal alluvial contact is below the lowest elevation of the modern-day thalweg, indicating that the alluvial system has aggraded to form the modern-day Savannah River.

In addition to the physical data, several suppositions can be made concerning the Quaternary geologic and geomorphic history of the Savannah River. The absolute timing and complex mechanisms that gave rise to the Savannah River alluvial valley still are unclear, although the relative timing and general response of the river to these mechanisms is apparent. The Savannah River was, at one time, located immediately adjacent to and northeast of the modern-day floodplain as indicated by the alluvial terrace complex identified as Qal 2. During the formation of Qal 2, the river load generally was coarser than when Qal 1 was later deposited. In addition, Qal 2 was formed by a cyclic pattern of entrenchment and subsequent infilling, which gave rise to an irregular basal contact. This depositional terrace system likely was formed during an extended period of time when the amount of sediment produced by the basin was in flux. Consequently, the incoming sediment load sometimes exceeded the amount that the river system could carry away. The conditions that initiated this cyclic cutting and filling are unclear, but could be a function of several factors, including climate change, changes in base level, slope, or load resulting from rising sea levels; rising local or regional base levels; or an influx of coarse load because of uplift in source area(s) (Ritter, 1986).

After the depositional period that formed Qal 2, the river migrated to the southwest and began a period of downcutting that continued until the river reached maximum incision illustrated by the longitudinal section D-D' (Figure 7). When this incision occurred, the river began a lateral planation, best exemplified by section A-A' (Figure 4) which eventually gave rise to the relatively flat basal contact (erosional terrace) that lies beneath Qal 1. This type of planation characterizes the classic equilibrium situation where the development of the basal unconformity requires extended time, and suggests a long period of stability during which base level and channel functions are constant and vertical disruptions by filling or cutting are absent (Ritter, 1986). An estimate of the period of stability implied by these conclusions is not possible given the current lack of data concerning the absolute age of sediments in the study area. The equilibrium condition eventually ended and a period of vertical aggradation occurred. This infilling resulted in the accumulation of Qal 1 and the formation of the modern-day floodplain, which lies well above the lowest incision that the river ever attained.

Examination of geologic sections D-D' (Figure 7) and E-E' (Figure 8) indicates that for both of the alluvial units, the alluvial valley fill thins in a downstream direction. This is significant because this phenomenon has remained constant over time and is most likely a function of the change in slope which occurs when the river traverses the Fall Line. At the Fall Line, the slope of the river is about 10.6 ft./mi in contrast to the typical 2.9 ft./mile above the Fall Line (Hack, 1982) and 0.99 ft./mi below the Fall Line. This change in slope could also be a result of (1) bedload reduction from changes in the river hydraulics; (2) loss of water resulting from differences in porosity between Piedmont and Coastal Plain bedrock; (3) an increase in the width of the floodplain; and (4) consequent reduction in channel depth. These four conditions constitute the simplest explanation for the changes in alluvial thickness; however, tectonic influence or long-term sea-level fluctuations also can account for changes in alluvial thickness.

Transect data indicates an east-to-west asymmetry in the alluvial terrace complex and the underlying bedrock strath. This asymmetry is a consequence of the protracted lateral migration of the Savannah River to the southwest. Cox (1994) categorized various processes to explain internal fluvial processes (for example, progressive shifting of a stream away from gravel-

Savannah River Site, Aiken, S.C., no. WSRC-RP-90-1010, variously paged.

Brooks, M.J., and Colquhoun, D.J., 1991, Late Pleistocene-Holocene depositional change in the Coastal Plain of the Savannah River Valley: a geoarchaeological perspective: Early Georgia, v. 19, no. 2, p. 1-20.

Brooks, Rebekah, Clarke, J.S., and Faye R.E., 1985, Hydrogeology of the Gordon aquifer system of east-central Georgia: Georgia Geologic Survey Information Circular 75, 41 p.

Clark, W.Z. and Zisa, A.C., 1976, Physiographic map of Georgia: Georgia Geologic Survey, 1 map, SM-4, scale 1:2,000,000.

Clarke, J.S., Brooks, R., and Faye, R.E., 1985, Hydrogeology of the Dublin and Midville aquifer systems of east central Georgia: Georgia Geologic Survey Information Circular 74, 62 p.

Colquhoun, D.J., 1981, Variation in sea level on the South Carolina Coastal Plain, in Colquhoun, D.J., *ed.*, Variation in sea level on the South Carolina Coastal Plain: International Geological Correlation Program 61, p. 1-44.

Colquhoun, D. J., 1990, Cosuna II: AAPG regional stratigraphic cross section easter and offshore South Carolina and Georgia: American Association of Petroleum Geologists, scale 1:250,000.

Colquhoun, D.J. and Johnson, H.S., Jr., 1968, Tertiary sea level fluctuation in South Carolina: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 5, p. 105-126.

Cooke, C.W., 1936, Geology of the Coastal Plain of South Carolina: U.S. Geological Survey Bulletin 867, 196 p.

Cox, R.T., 1994, Analysis of drainage-basin symmetry as a rapid technique to identify areas of possible Quaternary tilt block tectonics: an example from the Mississippi Embayment: Geological Society of America Bulletin, v. 106, p. 571-581.

Crissman, S.C., 1973, Neuse River flood plain development, Johnston and Wayne Counties, North Carolina: Durham, N.C., Duke University, unpublished master's thesis, 62 p.

Dennehy, K.F., Prowell, D.C., and P.B. McMahon, 1989, Reconnaissance hydrogeologic investigation of the Defense Waste Processing Facility and vicinity, Savannah River Plant, South Carolina: U.S. Geological Survey Water-Resources Investigations Report 88-4221, 74 p.

Domoracki, W.J., Coruh, C., Costain, J.K. and D.E. Stephenson, 1994, Faulting in Atlantic Coastal Plain sediments at the Savannah River Site, S.C.: Interpretation from seismic reflection time maps: Geological Society of America, abstracts with programs, Southeastern Section, p. 11.

Dubar, Neogene stratigraphy of the Lower Coastal Plain Geological Association, 12th Field Conference, Myrtle Beach, S.C., 128 p.

Dubar, J.R., Johnson, H.S., Jr., Thom B.G., and Hatchell, W.O., 1974, Neogene stratigraphy and morphology, south flank of the Cape Fear arch, North and south Carolina, *in* Oaks, R.Q., Jr., and DuBar, J.R., *eds*., Post-Miocene stratigraphy, Central and Southern Atlantic Coastal Plain: Logan, Utah State University Press, p. 139-173.

Fallaw, W.C. and Price, Van, 1992, Geological investigations of the central Savannah River area, South Carolina and Georgia: Augusta, Ga., Carolina Geological Society, field-trip guidebook 1992, variously paged.

Faye, R.E., and Prowell, D.C., 1982, Effects of Late Cretaceous and Cenozoic faulting on the geology and hydrology of the Coastal Plain near the Savannah River, Georgia, and South Carolina: U.S. Geological Survey Open-File Report 82-156, 72 p.

Geomatrix, 1993, Preliminary Quaternary and neotectonic studies Savannah River Site, South Carolina: Westinghouse Savannah River Company Report 1988, 59 p.

Hack, J.T., 1982, Physiographic divisions and differential uplift in the Piedmont and Blue Ridge: U.S. Geological Survey Professional Paper 1265, 49 p.

Hanson, K.L. and Bullard, T.E., 1992, Quaternary and neotectonic program *in* Field-Trip Guidebook: Earth Science Advisory Committee meeting. Augusta, Ga.

Hoel, D.D., 1983, Climatology of the Savannah River Plant Site: Aiken, S.C., E.I. du Pont de Nemours and Co., Savannah River Laboratory, DPST-83-705, 315 p.

Huddlestun, P.F., and Hetrick, J.H., 1986, Upper Eocene stratigraphy of central and eastern Georgia: Georgia Geologic Survey Bulletin 95, 78 p.

Logan, W.R., and Euler, G.M., 1989, Geology and groundwater resources of Allendale, Bamberg, and Barnwell Counties and part of Aiken County, South Carolina: South Carolina Water Resources Commission Report 155, 113 p.

Markewich, H.W., Hacke, C.M., and Huddlestun, P.F., 1989, Emergent Pliocene and Pleistocene sediments of southeastern Georgia: an anomalous fossil-poor clastic section, *in* Fletcher, C.H. and Wehmiller, J.F., *eds*., Quaternary Coasts of the United States: marines and lacustrine systems: Society of Economic Paleontologists and Mineralogists, special pub. no. 48, p. 173-189.

McCartan, L., Lemon, E.M., Jr., Weems, R.E., 1984, Geologic map of the area between Charleston and Orangeburg, South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I-1472, scale 1:250,000.

McClelland, Scott, 1987, Surface and subsurface stratigraphy of Cretaceous and younger strata along the Savannah River from southern Richmond County through Burke County, Georgia: Columbia, S.C., University of South Carolina, unpublished master's thesis, 79 p, 3 plates.

Monrad, J.R., 1972, Pee Dee River flood plain development, Marlboro and Darlington counties: Durham, N.C., Duke University, unpublished master's thesis, 75 p.

Nystrom, P.G., 1992, Middle and Late Wisconsinan radiocarbon dates of peat in Upper Three Runs and Tinker Creek alluvial sediments: constraints on rates of incision and sedimentation, *in* W. Fallaw and V. Price,

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THE CORBIN GNEISS: EVIDENCE FOR GRENVILLIAN MAGMATISM AND OLDER CONTINENTAL BASEMENT IN THE SOUTHERNMOST BLUE RIDGE

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ABSTRACT

The Corbin Gneiss Complex is located in northern Georgia within the southernmost Blue Ridge province of the Appalachians. The dominant lithology is a porphyroclastic orthogneiss. U-Pb zircon data indicate that the orthogneiss was derived from a protolith with a minimum $^{206}Pb/^{238}U$ age of 1106 ± 13 Ma. Later tectonothermal events were sufficient to reset the U-Pb systematics of some zircons to ages as young as 950 Ma. A depleted mantle Nd model age of 1590 Ma indicates that the protolith was derived at least in part from pre-Grenvillian crust.

INTRODUCTION

In recent years, several new global tectonic models for the Neo- and Mesoproterozoic have been proposed (e.g., Dalziel, 1991; Moores, 1991; Hoffman, 1991). As interest in Proterozoic tectonics grows, it has become increasingly important to define the lithologic, geochemical, isotopic, and geochronologic characteristics of the continental blocks taking part in tectonic processes so that the models can be adequately evaluated. For reconstructions involving the eastern margin of North America, it is particularly important to constrain the nature of the native Laurentian basement that extends the length of the Appalachian orogen.

The Blue Ridge lithotectonic province is recognized as one of the largest exposures of native Laurentian crust within the Appalachians (Rankin and others, 1993). In the southern Blue Ridge, most reported U-Pb zircon crystallization ages for meta-igneous rocks are in the range of 1.0 to 1.15 Ga, generally corresponding to the main (Ottawan) phase of the Grenville orogeny (Rankin and others, 1993). The majority of these ages are from the Shenandoah massif in Virginia and reliable data, particularly U-Pb zircon ages, for units to the south are less abundant (Rankin and others, 1993). The scarcity of geochronologic and geochemical data for the southernmost Blue Ridge makes it difficult to evaluate models for the evolution of Grenville-age terranes in the southernmost Appalachians. Furthermore, it hinders evaluation of models for the origin and accretion of exotic blocks such as the Carolina, Inner Piedmont, and Suwannee Terranes because such evaluations rely heavily on comparison between the pre-Neoproterozoic basement of these terranes and those cratons from which they may have been derived (e.g., West Africa, Amazonia, or Laurentia).

$^{40}Ar/^{39}Ar$ age of 702 ± 15 Ma for biotite concentrates from the orthogneiss phase of the Corbin Gneiss and interpreted this age as the result of very slow cooling following Grenville (~1 Ga) metamorphism. Alternatively, this age could be interpreted as the result of partial resetting of Grenvillian biotites. In addition, Paleozoic K-Ar and $^{40}Ar/^{39}Ar$ ages have been reported for the Corbin Gneiss south of the study area. These ages have been interpreted as cooling ages associated with Paleozoic orogenic events (Smith and others, 1969; Dallmeyer, 1975; McConnell and Costello, 1984).

The location of the Corbin Gneiss Complex, near the southern terminus of the Blue Ridge and close to the proposed Laurentian margin, makes it a particularly key lithologic unit whose age and origin is pertinent to global tectonic models. In this study, we report new U-Pb zircon age and Nd and Sr isotopic data for the Corbin Gneiss, along with major and trace element abundances for the geochronologic sample, which we compare with previously published geochemical data for the Corbin Gneiss Complex (Martin, 1974; McConnell and Costello, 1989; Higgins and others, 1988).

SAMPLES AND MINERALOGY

The sample chosen for this study was obtained from an exposure along Georgia Route 20, 1.8 miles west of the Cherokee County - Bartow County line (Figure 1; Costello, 1986). At this locality, the Corbin Gneiss is a blue-gray, coarse-grained, porphyroclastic gneiss with abundant megacrysts of microcline. Martin (1974) described this phase of the gneiss complex as an orthogneiss based on its igneous-like mineral assemblage and major element composition; McConnell and Costello (1984) defined it as the volumetrically dominant lithology of the Corbin Gneiss. In thin-section, the mineralogy consists primarily of microcline, plagioclase (oligoclase-andesine), quartz (bluish-gray in hand sample), biotite, and garnet, and has a locally developed augen texture. The garnet is heavily corroded and hosts several retrograde alteration minerals. Minor constituents include ilmenite rimmed with leucoxene, apatite, muscovite, rutile (found as oriented needles in large grains of biotite as a sagenitic texture), and zircon. Alteration minerals present include chlorite, calcite (found along fractures and associated with small grains of quartz), secondary white mica (sericite), and zoisite which has saussuritized the plagioclase. Symplectic quartz exsolution textures occur at the contact between the microcline and the plagioclase, and perthitic exsolution is common in the microcline. Some of these textures may result from syndeformation strain-enhanced reactions rather than chemical disequilibrium (Simpson and Wintsch, 1989). Based on point-counted modal abundances of quartz (30%), plagioclase (25%), and microcline (35%), the composition of this sample is granitic (Streckeisen, 1976).

Zircons separated from the Corbin orthogneiss exhibit a wide range of sizes and shapes, from euhedral, zoned crystals to unzoned, anhedral grains. The anhedral grains are rarely round, however, and the morphology of the grains seems most compatible with an igneous origin. Mylonitization, accompanying metamorphism, has resulted in some rounding of grains, as well as the grown of new grains and visible overgrowths on older grains (Table 1).

ANALYTICAL TECHNIQUES

Abundances of the major elements were determined by wavelength-dispersive X-ray fluorescence (XRF) spectrophotometry at XRAL Activation Services Inc. Abundances of the trace elements Zr, Nb, Y, V, Ba, Sc, and Cr were determined at the University of Florida by wavelength-dispersive X-ray fluorescence (Heatherington and Mueller, 1991). Abundances of rare earth elements, Co, Br, Sb, Cs, Hf, Ta, Th, and U were determined by instrumental neutron activation (INAA) analysis at Auburn University. Whole-rock Nd and Sr isotopic data were obtained by standard procedures at UF (Heatherington and Mueller, 1991).

U-Pb geochronologic analysis of zircons was undertaken by both conventional thermal ionization mass spectrometry (TIMS) and sen-

Table 2. Whole-rock elemental and isotopic analyses of the Corbin Gneiss. XRF: analyses by X-ray fluoresecence. INAA: analyses by instrumental neutron activation. T dm: depleted mantle Nd model age.

XRF Analyses*		INAA Analyses*		Isotopic data	
SiO2	67.2	Co	5.13	87Sr/86Sr	0.73678
TiO2	0.84	Br	0.34	Rb †	254.2
Al2O3	14.7	Rb	208	Sr†	231
CaO	2.86	Sr	249	87Rb/86Sr	3.184
MgO	0.67	Sb	0.077	87Sr/86Sr (1106 Ma)	0.68666
Na2O	2.5	Cs	0.756	143Nd/144Nd	0.512038
K2O	5.25	La	78.2	Nd†	92.3
Fe2O3	4.52	Ce	177	Sm†	17.9
MnO	0.07	Nd	112	147Sm/144Nd	0.11751
Cr2O3	0.01	Sm	16.7	ε Nd	-11.7
P2O5	0.42	Eu	2.87	143Nd/144Nd (1106 Ma)	0.511190
LOI	0.65	Tb	2.02	ε Nd (1106 Ma)	-0.55
Total	100	Yb	2.32	T dm	1590 Ma
Nb	24.3	Lu	0.33		
Y	33.4	Hf	18.1		
Zr	622	Ta	1.67		
V	36.8	Th	3.1		
Ba	1326	U	1.23		
Sc	11.2				
Cr	31.0				

*concentrations of major element oxides are in weight percent; concentrations of trace elements are in ppm
†concentration (ppm) determined by isotope dilution

At the very low common Pb contents observed, however, calculated $^{206}Pb/^{238}U$ ages are largely insensitive to the choice of common Pb composition and correction method. In Mesoproterozoic or younger rocks containing zircons of moderate U-content, ages based on the $^{206}Pb/^{238}U$ system are generally preferred over those produced using either the $^{207}Pb/^{235}U$ system or the combination of the two systems ($^{207}Pb/^{206}Pb$). This is a consequence of the low abundance of ^{207}Pb, which results in poor counting statistics for this isotope and lower precision for ages involving the $^{207}Pb/^{235}U$ system (Table 1). The $^{206}Pb/^{238}U$ ages are more precise by a approximately a factor of 2 and provide more useful minimum ages.

Age errors for both TIMS and SHRIMP analyses are given at 2σ in Table 1 and were calculated using the recommended decay constants of Steiger and Jager (1977).

RESULTS

Geochemistry

The bulk composition of the sample chosen for this study is representative of the orthogneiss phase of the Corbin Gneiss as described by thirty major element analyses reported by McConnell and Costello (1984, after Martin, 1974) and four additional analyses reported by Higgins and others (1988) (Table 2; Figure 2).

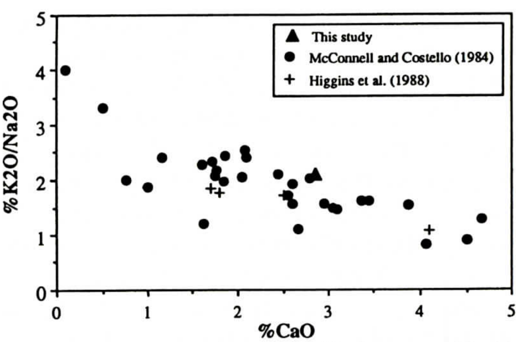

Figure 2. Plot of weight percent K_2O/percent Na_2O as a function of weight percent CaO for analyses of Corbin orthogneiss presented in this study and in McConnell and Costello (1984, after Martin, 1974).

A plot of $\%K_2O/\%Na_2O$ versus %CaO for the samples of McConnell and Costello (1984) and Higgins and others (1988) reveals a regular negative correlation indicative of igneous fractionation. The analyzed sample plots near the mid-range of the distribution (Figure 2). General preservation of original CaO-K_2O-Na_2O relations strongly suggests that less mobile elements also preserved their original distribu-

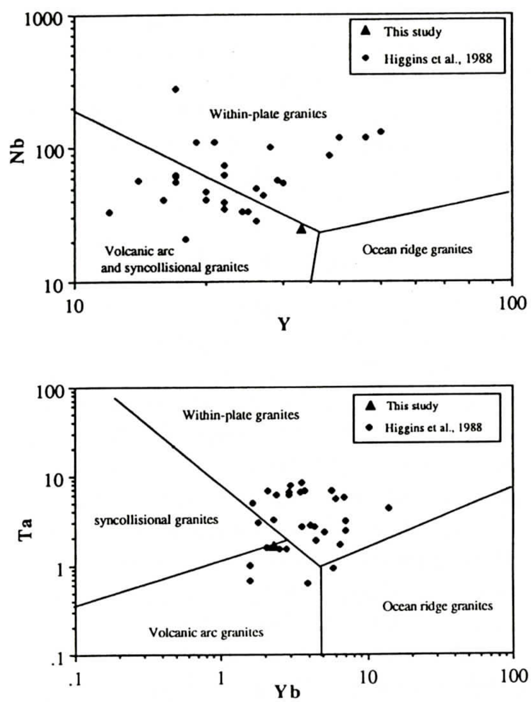

Figure 5.- Nb, Y, Ta, and Yb abundances (ppm) for Corbin Gneiss plotted on tectonic discrimination diagrams for granitoids from Pearce and others (1984).

have $^{206}Pb/^{238}U$ ages of 996 ± 12 Ma, 1016 ± 4 Ma, 1020 ± 2 Ma, and 1026 ± 10 Ma. The two discordant fractions have $^{207}Pb/^{206}Pb$ ages of 1036 ± 5 and 1035 ± 3 Ma, and $^{206}Pb/^{238}U$ ages of 1007 ± 4 and 943 ± 3 Ma, respectively (Table 1 and Figure 7).

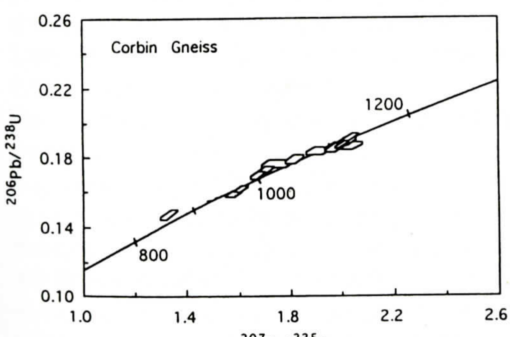

Figure 6.- Concordia diagram for fourteen SHRIMP U-Pb analyses on twelve zircon grains obtained from the Corbin Gneiss. Ages on concordia curve are in Ma. Error envelopes are 1-sigma.

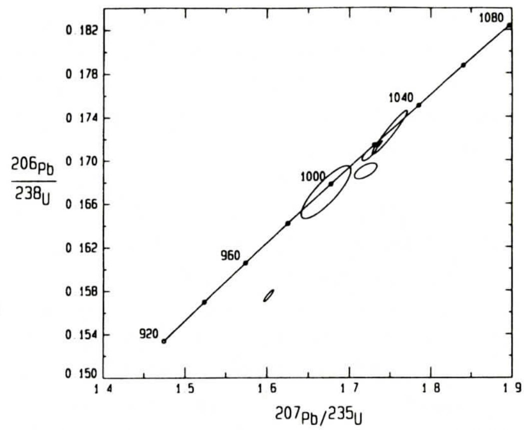

Figure 7.- Concordia diagram for six TIMS U-Pb analyses on multigrain zircon samples obtained from the Corbin Gneiss. Ages on concordia curve are in Ma. Error envelopes are 2-sigma.

All but three of the SHRIMP and TIMS analyses are within two sigma of being concordant. It is apparent from the large range in ages for concordant grains, and the core-rim age relationships, that the growth of new zircon and/or Pb loss took place for a period of over 100 Ma after formation of the first zircons. The absence of observed ages greater than 1036 Ma for TIMS analyses may be a result of averaging the ages of younger and older grains, and younger and older portions within individual grains, due to the fact that each TIMS sample consisted of several zircons. Consequently, the best age estimate that can be given for the time of crystallization of the protolith of this gneiss is based on the seven oldest $^{206}Pb/^{238}U$ SHRIMP ages (1087 to 1130 Ma; average = 1106 ± 13 Ma; Table 1). Although the choice of these seven grains was somewhat arbitrary, their average age clearly represents the minimum age of the protolith of the gneiss. Younger ages are probably the result of growth of new zircon and/or ancient Pb-loss, i.e., Pb lost early in the history of the grain when Pb-loss trajectories are essentially parallel to concordia (Bowring and others, 1989; Mueller and others, 1992). Pb-loss of this type can be associated with granulite facies metamorphism similar to that which affected the Corbin Gneiss.

The timing of the event(s) responsible for pre-Grenvillian material, such as that proposed for the Mars Hill terrane or the mid-continent granite-rhyolite province (Nelson and DePaolo, 1985; Shuster and others, 1992). This inference of pre-Grenvillian crust in northern Georgia extends the range of pre-Grenvillian crust within the Blue Ridge farther south than previously recognized.

Several reports of pre-Grenvillian material have been made for the Virginia and North Carolina portions of the Blue Ridge. Sinha and Bartholomew (1984) reported U-Pb zircon evidence for a component up to 1860 Ma within the metasedimentary Stage Road Gneiss in the Shenandoah massif of the Virginia Blue Ridge; Pettingill and others (1984) suggested a possible age of 1490 Ma for the source of the Pedlar River Charnockite, also in the Virginia Blue Ridge; Herz and Force (1984) reported a $^{207}Pb/^{206}Pb$ age of 1787 Ma for zircons from the Shaeffer Hollow granite in the Roseland district of Virginia; McConnell and others (1991) reported Pb-Pb ages of 1520 Ma for xenocrystic zircons from the Grassy Creek gneiss in the Sauratown Mountains window of north-central North Carolina; and Su and others (1994) reported a U-Pb concordia upper intercept age of 1424 ± 29 Ma for premagmatic zircons from the Beech metagranite in the Crossnore Complex of western North Carolina. Likewise, Sm-Nd isotopic data from locations within the Blue Ridge province also suggest the presence of basement older than 1.5 Ga (Jenks and Sinha, 1991; Fullagar and others, 1994). Collectively, these data suggest that the pre-Grenvillian component in the southern Blue Ridge lithotectonic province may be quite widespread.

CONCLUSIONS

Data presented here confirm the Grenvillian age for the protolith of the Corbin Gneiss orthogneiss. The protolith crystallized no later than 1106 ± 13 Ma, coinciding with the main (Ottawan) phase of the Grenville orogeny, as it has been defined for the Adirondacks (Moore, 1986; Rankin and others, 1993). It was later subjected to tectonothermal events that caused growth of new zircon and/or partial resetting of the U-Pb system in some zircons. These events include granulite facies metamorphism, possibly at 1013 to 1061 Ma, and increased thermal gradients associated with Neoproterozoic rifting. In addition, Sm-Nd systematics suggest the presence of pre-Grenvillian lithosphere in the source of the Corbin Gneiss protolith.

ACKNOWLEDGMENTS

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REFERENCES CITED

Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, P.T., and Burton, W.C., 1995, U-Pb ages of metarhyolites of the Catoctin and Mount Rogers Formations, central and southern Appalachians: evidence for two pulses of Iapetan rifting: American Journal of Science, v. 295, p. 428-454.

Bartholomew, M.J. and Lewis, S.E., 1988, Peregrination of Middle Proterozoic massifs and terranes within the Appalachian Orogen, Eastern U.S.A.: Trabajos de Geologia, v. 17, p. 155-165.

Bartholomew, M.J. and Lewis, S.E., 1992, Appalachian Grenville massifs: Pre-Appalachian translational tectonics *in* Mason, R., ed. International Basement Tectonics Association Publication No. 7., p. 363-374.

Bowring, S.A., Grotzinger, J.P., Isachsen, C.E., Knoll, A.H., Pelechaty, S.M., Kolosov, P., 1993, Calibrating rates of Early Cambrian evolution: Science, v. 261, p. 1293-1298.

Bowring, S.A., Williams, I.S., and Compston, W., 1989, 3.96 Ga gneisses from the Slave province, Northwest Territories, Canada: Geology, v. 17, p. 971-975.

Carter, M.W., Geddes, D.J., Hatcher, R.D., Jr., and Martin, S.L., 1995, Field trip guide to the stratigraphic and structural relationships in the western Blue Ridge foothills of southeastern Tennessee, *in* Hatcher R.D., ed., Guidebook for Field Trips in the Southern Appalachian Internides, Geological Society of America, Southeastern Section, p. 24-56.

Clemens, J.D., Holloway, J.R., and White, A.J.R., 1986, Origin of an A-type granite: experimental constraints:

continental crust 1.7 to 1.9 b.y. ago: Nd isotopic evidence from the basement of the North American mid-continent: Geological Society of America Bulletin, v. 96, p. 746-754.

Odom, A.L. and Fullagar, P.D., 1984, Rb-Sr whole-rock and inherited zircon ages of the plutonic suite of the Crossnore Complex, southern Appalachians, and their implications regarding the time of opening of the Iapetus Ocean, *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and Related Topics: Geological Society of America Special Paper 194, p. 229-254.

Odom, A.L., Kish, S.A., and Leggo, P.J., 1973, Extension of "Grenville basement" to the southern extremity of the Appalachians: U-Pb ages of zircons: Geological Society of America Abstracts with Programs, v. 5, p. 425.

Parrish, R.R., 1987, An improved micro-capsule for zircon dissolution in U-Pb geochronology: Chemical Geology, v. 66, p. 99-102.

Pearce, J.A., Harris, N.B.W., and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 25, p. 956-983.

Pettingill, H.S., Sinha, A.K., and Tatsumoto, M., 1984, Age and origin of anorthosites, charnockites, and granulites in the central Virginia Blue Ridge: Nd and Sr isotopic evidence: Contributions to Mineralogy and Petrology, v., 85, p. 279-291.

Rankin, D.W., Stern, T.W., McLelland, J., Zartman, R.E., and Odom, A.L., 1983, Correlation chart for Precambrian rocks of the eastern United States, *in* Harrison, J.E., and Peterman, Z.E., eds., Correlation of Precambrian rocks of the United States and Mexico: U.S. Geological Survey Professional Paper 1241, p. E1-E10.1983

Rankin, D.W., Chiarenzelli, J.R., Drake, A.A., Goldsmith, R., Hall, L.M., Hinze, W.J., Isachsen, Y.W., Lidiak, E.G., McLelland, J., Mosher, S., Ratcliffe, N.M., Secor, D.T., Jr., and Whitney, P.R., 1993, Proterozoic rocks east and southeast of the Grenville front, *in* Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds., Precambrian: Conterminous U.S., v. C-2: The Geology of North America, The Geological Society of America, p. 335-462.

Shuster, R.D., Mueller, P.A., and Heatherington, A.L., 1992, Geochemical evidence concerning the nature of the source region of the Middle Proterozoic granite-rhyolite province: Geological Society of America Abstracts with Programs, v. 24, A93.

Silver, L., 1969, A geochronological investigation of the anorthosite complex, Adirondack Mountains, New York, *in* Isachsen, Y., ed., Origin of anorthosites and related rocks: New York State Museum Memoir 18, p. 233-252.

Simpson, C. and Wintsch, R.P., 1989, Evidence for deformation-induced K-feldspar replacement by myrmekite: Journal of Metamorphic Geology, v. 7, p. 261-275.

Sinha, A.K. and Bartholomew, M.J., 1984, Evolution of the Grenville terrane in the central Virginia Appalachians *in* Bartholomew, M.J., ed., The Grenville event in the Appalachians and Related Topics: Geological Society of America Special Paper 194, p. 175-186.

Smith, J.W., Wampler, J.M., and Green, M.A., 1969, Isotopic dating and metamorphic isograds of the crystalline rocks of Georgia, *in* Precambrian-Paleozoic Appalachian field problems: Georgia Geological Survey Bulletin 80, p. 121-139.

Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology; Earth and Planetary Science Letters, v. 36, p. 359-362.

Streckeisen, A.L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.

Su, Q., Goldberg, S.A., and Fullagar, P.D., 1994, Precise U-Pb zircon ages of Neoproterozoic plutons in the southern Appalachian Blue Ridge and their implications for the initial rifting of Laurentia: Precambrian Research, v. 68, p. 81-95.

Sylvester, P.J., 1989, Post-collisional alkaline granites: Journal of Geology, v. 97, p. 261-280.

Whalen, J.B., Currie, K.L., and Chappell, B.W., 1987, A-type granites: geochemical characteristics, discrimination and petrogenesis: Contributions to Mineralogy and Petrology, v. 95, p. 407-419.

SOUTHEASTERN GEOLOGY
V. 36, No. 1, April 1996, p. 27-35

LOWER MISSISSIPPIAN SEDIMENTATION DYNAMICS AND CONODONT BIOSTRATIGRAPHY (LOWERMOST FORT PAYNE FORMATION) ALONG THE SOUTHEASTERN MARGIN OF THE EASTERN INTERIOR SEAWAY

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ABSTRACT

Conodont biostratigraphy of a 28-32 cm thick glauconitic shale bed at the base of the Fort Payne Formation (Maury equivalent) immediately above the Chattanooga Shale on Highway 61, 4.6 miles south of State Route 90, near Burkesville, Kentucky substantiates the model of starved basin, continuous sedimentation conditions from Kinderhookian through the middle Osagean. The glauconitic shale bed is, apparently, the record of 17.5 million years of sedimentation, whereas the 81.7 m of the remainder of the Fort Payne Formation was deposited in approximately 2 million years. Crinoids and conodonts from the overlying Fort Payne Formation indicate a late Osagean age. The base of the glauconitic shale bed is Kinderhookian and contains a conodont fauna that is no older than the lower *Siphonodella duplicata* zone. *Gnathodus pseudosemiglabar* within the upper part of the glauconitic shale bed indicates that in this area its top is no older than middle *Scoliognathus anchoralis* - *Doliognathus latus* zone (middle Osagean). The age of the glauconitic shale bed cannot be constrained any more precisely because of redeposited conodonts, some of which are biochemically darkened, abraded, and in all but the lowermost sample hydraulically sorted. This supports the idea that the conodonts laid exposed on the sea floor for extended periods of time before final deposition and burial. These biostratigraphic data also support the idea that the Eastern Interior (Illinois) Basin was a topographic basin that filled as prograding units migrated westward.

INTRODUCTION

The Fort Payne Formation is an extensive, heterogeneous sequence of Lower Mississippian strata. Geographically, it extends from northwestern Georgia to southern Illinois. In south-central Kentucky it is more than 90 m thick and contains a mixed suite of autochthonous and allochthonous carbonates and siliciclastics (Lewis and Potter, 1978; Ausich and Meyer, 1990). The facies diversity and volume of the Fort Payne have resulted in conflicting interpretations regarding deposition and stratigraphic relationships. Was the Fort Payne deposited in shallow water (Chowns and Elkins, 1974; MacQuown and Perkins, 1982), or was it an epicontinental basin-filling sequence (Pryor and others, 1974; Lewis and Potter, 1978; Ausich and Meyer, 1990)? What stratigraphic relationships exist between the Fort Payne Formation and adjacent and subjacent units, e.g. contrast Sedimentation Seminar (1972) with Lumsden (1988)? What was the mer, 1994) and by the phosphate nodules and glauconitic composition (Hass, 1956; Conant and Swanson, 1961).

The Fort Payne of south-central Kentucky is within the carbonate-bank regional facies of Lewis and Potter (1978), one of five regional facies recognized. Ausich and Meyer (1990) and Meyer and Ausich (1992) recognized a variety of facies, including background siltstones, green fossiliferous shale, the Jabez Sandstone, allochthonous sheet-like packstones, allochthonous channelform packstones, autochthonous wackestone buildups, and autochthonous crinoidal packstone buildups. The siltstone facies comprises the majority of the Fort Payne, volumetrically, the Jabez Sandstone occurs higher within the Fort Payne, and the other facies are more common within the lower part of the Fort Payne.

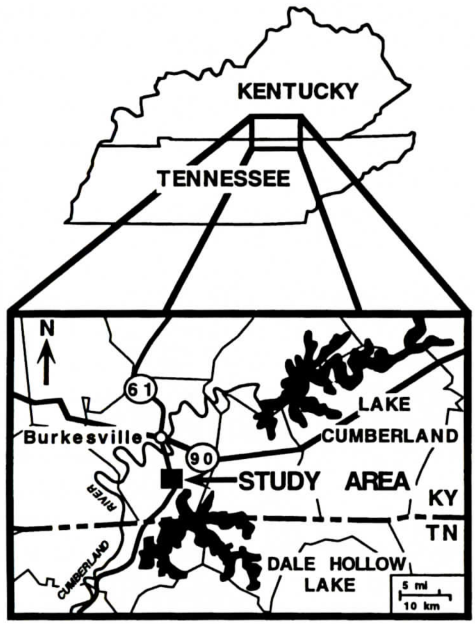


Figure 1.-Index map showing study area.

Cumberland County

A complete section of the Fort Payne is exposed in a series of road cuts along Kentucky Highway 61, 4.6 miles (6.6 km) south of State Route 90, near Burkesville, Kentucky (Figure 1). The base of these exposures is in the Late Ordovician Cumberland Formation, unconformably overlain by the Late Devonian Chattanooga Shale. The Fort Payne is conformable above the Chattanooga. At this exposure the Fort Payne is approximately 81.7 m thick, and a large wackestone buildup occurs approximately 6.7 m above the base of the Fort Payne (Thies, 1988; Meyer and others, In press). The Fort Payne along Highway 61 is composed of interbedded allochthonous packstones, siltstones, and fossiliferous green shales.

The lower 28-32 cm of the Fort Payne is composed of glauconitic shale with phosphate nodules, herein referred to as the glauconitic shale bed. The glauconitic shale bed is considered part of the Fort Payne Formation in Kentucky (Lewis, 1967) and it may be in part correlative with the Floyds Knob Bed (Kepferle, 1979). This interval in Tennessee is termed the Maury Shale (Hass, 1956; Conant and Swanson, 1961; Sable and Dever, 1990). The base of the glauconitic shale bed is gradational with the underlying Chattanooga Shale. The uppermost part of the Chattanooga Shale also contains abundant phosphatic nodules and becomes increasingly lighter in color, from black to medium brown, near its top. The apparent gradational nature of the contact with the overlying glauconitic shale bed suggests that if there is any time missing between the Chattanooga Shale and the Fort Payne Formation, it is a relatively brief hiatus that is on the order of a diastem.

BIOSTRATIGRAPHY

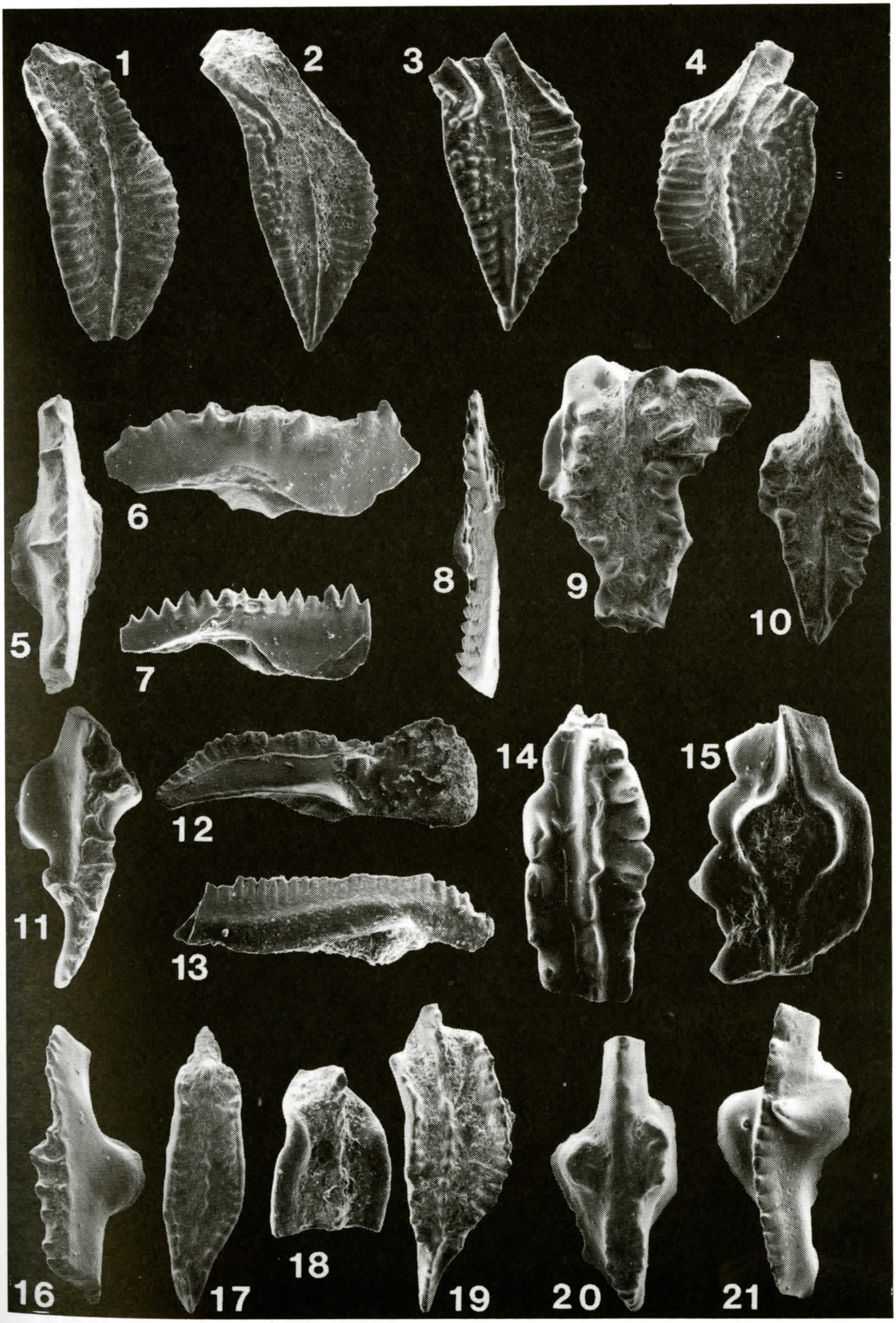
Pioneer conodont work by Hass (1956) indicated that in Tennessee the "Maury is chiefly of Kinderhook age; however, the youngest beds of the formation are probably of Osage age and the oldest beds in part of north-central Tennessee are probably of very late Devonian age." Collinson and others (1962) showed the extent of the Maury to exactly equal the duration of the Kinderhookian. In this study, seven samples were collected for conodonts from the *cata* serves to constrain the age because there is no evidence of redeposition in 93SAL10-5 or in the samples below. Redeposition of conodonts is apparent in the upper part of the glauconitic shale bed (Figure 2). It is easily demonstrated in 93SAL10-2 and 93SAL10-4, where species of *Siphonodella*, all of which are restricted to the Kinderhookian (except for the Famenian species *S. praesulcata*), occur with *Gnathodus pseudosemiglabar*, a species that first appears in the middle Osagean *Scoliognathus anchoralis - Doliognathus latus* zone (Lane and others, 1980). Even though the uppermost sample in the glauconitic shale bed contains redeposited conodonts, its maximum age can be assessed. The occurrence of *G. pseudosemiglabar* within the glauconitic shale bed indicates that its top is no older than middle *S. anchoralis - D. latus* conodont zone (Figure 2).

Above the basal glauconitic shale bed of the Fort Payne, all conodonts, crinoids, and blastoids recovered indicate a late Osagean, *Gnathodus texanus* zone, age, which is time equivalent to the Keokuk Limestone of the Mississippian stratotype section (Ausich and Meyer, 1988, 1990). The Kinderhookian - middle Osagean, *S. duplicata* to *S. anchoralis - D. latus* zone age of the glauconitic shale bed indicated by conodonts shows that this thin interval is time equivalent to the Hannibal Shale, Chouteau Group, Fern Glen Formation and Burlington Limestone of the Mississippian stratotype section (Thompson, 1979).

The age of the upper Chattanooga Shale cannot be precisely assessed from the samples collected. Only one conodont species, *Bispathodus stabilis*, was recovered from the upper part of the Chattanooga Shale. Unfortunately, *B. stabilis* is a long-ranging species that spans the Devonian-Mississippian boundary and is therefore of little biostratigraphic value. However, based on the occurrence of a diagnostic Mississippian fauna immediately above the Chattanooga Shale and the gradational aspect the Chattanooga-Fort Payne (glauconitic shale bed) contact (Figure 2), the base of the glauconitic shale bed of the Fort Payne is interpreted as nearly, if not coincident with, the base of the Mississippian in south-central Kentucky. This interpretation is consistent with that of Sable and Dever (1990) for the Eastern Interior Basin in south-central Kentucky.

INTERPRETATION

Previous studies (Hass, 1965) have suggested a Kinderhookian age for the Maury Shale and its equivalents, but the closely-spaced stratigraphic sampling with sequentially younger conodont zones demonstrates that, indeed, in the resolution of the new biostratigraphic data presented here, more or less continuous deposition occurred in south-central Kentucky from the Chattanooga Shale through the Fort Payne Formation. However, depositional rates fluctuated dramatically. Assuming that the base of Mississippian to the end of the late Osagean had a 19.7 million year duration (Harland and others, 1989, p. 10) and that the Chattanooga-Fort Payne boundary occurs at, or near, the Devonian-Mississippian boundary in Cumberland County, the lower 32 cm of the Fort Payne were deposited in approximately 17.5 million years, whereas the upper 81.7 m of the Fort Payne were deposited during the late Osagean (=Arundian), which is approximately 2.2 million years. This disparity with the demonstrated more or less continuous deposition substantiates the model that the Kinderhookian through middle Osagean was deposited in sediment-starved conditions in south-central Kentucky, represented by the glauconitic shale bed. This biostratigraphic conclusion is consistent with the phosphate nodules and glauconite present in the basal interval of the Fort Payne. However, it is possible that the earliest Kinderhookian is not represented. The age cannot be constrained any more precisely because of the absence of early Kinderhookian index species, such as *Siphonodella sulcata*, *Protognathodus meischneri* or *P. collinsoni*. The lowermost sample within the glauconitic shale bed is Kinderhookian based on the presence of *Siphonodella* sp. fragments.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Waulsortian facies: El Paso Geological Society and The University of Texas at El Paso, p. 34-42.

MacQuown, W.C. and Perkins, J.H., 1982, Stratigraphy and petrology of the petroleum-producing Waulsortian-type carbonate lenses and mounds in north-central Tennessee: American Association of Petroleum Geologists, Eastern Section, 5th annual Meeting Program, p. 24-25.

Matchen, D.L, and Kammer, T.W., 1994, Sequence stratigraphy of the Lower Mississippian Price and Borden Formations in southern West Virginia and eastern Kentucky: Southeastern Geology, v. 34, p. 25-41.

Meyer, D.L. and Ausich, W.I, 1992, Fort Payne carbonate facies (Mississippian) of south-central Kentucky: Ohio Division of Geological Survey Miscellaneous Report No. 4, 20 p.

Meyer, D.L., Potter, P.E., Thies, J.L., Ausich, W.I., and Leslie, S.A., In press, Fort Payne Formation (Lower Mississippian) on Kentucky 61 south of Burkesville, Cumberland County: Study and research section of a deep-to-shallow transition. Kentucky Map and Chart Series 1.

Peterson, W.L. and Kepferle, R.C., 1970, Deltaic deposits of the Borden Formation in central Kentucky: U.S. Geological Survey Professional Paper, No. 700-D, p. 49-54.

Pryor, W.A., Klein, H.H., and Hannan, A.E., 1974, Crinoidal bodies of submarine-debris-flow origin, Early Mississippian, south-central Kentucky: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists Annual Meeting Abstracts, v. 1, p. 72-73.

Rexroad, C.B., and Scott, A.J., 1964, Conodont zones in the Rockford Limestone and the lower part of the New Providence Shale (Mississippian) in Indiana: Indiana Geological Survey Bulletin No. 30, 54 p.

Sable, E.G., and Dever, G.R., Jr., 1990, Mississippian rocks in Kentucky: U.S. Geological Survey Professional Paper 1503, 125 p.

Sandberg, C.A., Ziegler, W., Leuteritz, K., and Brill, S.M., 1978, Phylogeny, speciation, and zonation of *Siphonodella* (Conodonta, Upper Devonian and Lower Carboniferous): Newsletters on Stratigraphy, v. 7, no. 2, p. 102-120.

Sedimentation Seminar, 1972, Sedimentology of the Mississippian Knifley Sandstone and Cane Valley Limestone in south-central Kentucky: Kentucky Geological Survey, series X, Report of Investigations 13, 30 p.

Thies, J.L., 1987, Analysis of crinoid communities and their associated lithofacies within the Fort Payne Formation (Lower Mississippian) in the vicinity of Burkesville, Kentucky (Cumberland County): University of Cincinnati, M.S. Thesis (unpublished), 171 p.

Thompson, T.L., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States-Missouri: U.S. Geological Survey Professional Paper 1110-N, 22 p.

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"THIS MAP IS ONLY A PRELIMINARY ONE, AND SHOULD NOT BE CONSIDERED ACCURATE IN ANY SENSE."

WEST VIRGINIA GEOLOGICAL SURVEY MAPS, 1899-1921

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ABSTRACT

Between 1899 and 1921, Israel Charles White and other staff members of the West Virginia Geological and Economic Survey compiled and published ten editions of a statewide mineral resources map. Although long out-of-print and extremely scarce, these maps illustrate the major coal areas, all coal mines, oil and gas wells and fields, limestone areas, and iron-ore locations. Each successive edition showed continuous improvements that reflected the growth of the State's viable mineral economy. The maps represent one of many programs initiated by White during his tenure as the first State Geologist.

INTRODUCTION

The title of this paper does not instill much confidence, particularly since it was written by the newly-appointed State Geologist, Israel Charles White, on a map that was the very first publication of the newly-formed West Virginia Geological and Economic Survey (Lessing, 1989a). However, he retained his position from 1897 until his death in 1927. The map, with its inauspicious first line of text, went through ten editions between 1899 and 1921. White's cautionary words were directed mainly at the base map, because without an accurate base, it was extremely difficult to plot the locations of the State's mineral resources with any degree of confidence. The base map for the first three editions was produced in 1898 by Russell L. Morris, Engineering Professor at West Virginia University. Although his sources are not known, he most likely used 1:125,000 scale U.S.G.S. topographic sheets, and available state and county maps by Wood, Boye, Corzet, von Buchholtz, Cram, Colton, and others. White recognized that accurate topographic maps were "...absolutely essential to the rapid and orderly development of the vast natural resources of our State..." and with these words, he made a proposal to the West Virginia Geological Survey Commission (White, 1898, p. 9) to begin a cooperative mapping program with the U. S. Geological Survey (U.S.G.S.).

The first edition of the mineral resources map was published with State funds, but the legislature failed to appropriate funds for the Survey for 1899 and 1900. Consequently, the second edition was printed privately by White with the topographic errors of the first edition. He used a block of text on the second edition to point out again the base-map problem, adding a plea for funding a cooperative mapping program.

"The very inaccurate topographic base of the map (which is the best that can be had at present), is recognized and regretted by none more than the authors. Hence, those who may find occasion to use it are hereby warned and cautioned that many of the towns and villages, as well as the streams, are probably placed several miles out of their true geographic position....the Coal areas, Oil and Gas pools, as well as the Anticlinal lines, may often be erroneously placed by a distance of several miles. We can only hope that some future Legislature will recognize how great would be the value to every citizen of the State of an accurate topographic map, and will make provision for the same in cooperation with the United States

Figure 2. Part of the first edition (1899) of White's mineral resources map shown at the original scale of one inch equal to ten miles. Note the hachures, lack of black dots for coal mines, very few oil and gas wells, and lack of anticlinal axes (compare with Figure 3). The dark gray pattern (right) is the Alleghany [sic] or Kanawha Coal Areas and the light striped pattern (left) is the Pittsburg Coal Areas.

West Virginia, surrounding states, and internationally. However, except for his first year as State Geologist, he never accepted a salary from the State. During his 30 years as State Geologist, White also served as Chief Geologist for the Brazilian Coal Commission (1904-1906); Treasurer (1892-1906), Councilor (1891), First Vice-President (1912), and President (1920) of the Geological Society of America; President of the American Association of Petroleum Geologists (1920); and President of the American Association of State Geologists (1913-1915). He died in Baltimore, Maryland on November 25, 1927 (Brown, 1936; Fairchild, 1928; Hennen, 1928; Lessing, 1988).

It can be argued that White's most significant contribution to Appalachian geology was his revival of the "anticlinal theory" of oil and gas accumulation. First proposed as a theory by T. Sterry Hunt in 1861, it fell into disfavor until the mid-1880s, primarily because of opposition by J. Peter Lesley, Director of the Second Geological Survey of Pennsylvania and White's former boss. White successfully used the anticlinal theory as an aid to the discovery of the Mannington oil field in West Virginia and later stated: "Guided by this principle, the writer pointed out and located all the great oil pools of West Virginia for a Pittsburg syndicate in 1884-1885, long before the drill finally demonstrated the correctness of his conclusions" (White, 1904, p. 54). The final confirmation, on the Gulf Coast of Texas, was Spindletop in 1901 which "...was the result of an understanding of the anticlinal theory and its application to a salt dome" (Galey, 1985, p. 440).

During White's tenure as State Geologist, he initiated numerous programs called for in the Act of February 26, 1897, that established the Survey. His most ambitious undertaking involved supervising the geological mapping of all 55 counties in the State at 1:62,500 scale as a series of 29 County Reports with accompanying text. Most of the authors noted on the various editions of the mineral resources maps were geologists employed by the Survey who quoted in the introduction.

A Map of West Virginia. By Russell Love Morris and Israel Charles White; 1:633,600 scale; August 1, 1901

With the Survey again funded by legislative action, the third edition came off the presses of A. Hoen. This map presents several problems, primarily because it has not been seen and no archival copies are known. The map is noted by White in his biennial report (1902) and is listed for sale at $0.50. However, in all other reports to the legislature and on all Lists of Publications, there are no further mentions of this map. The map would probably be more similar to the first edition than to the second, primarily because of the assumed reintroduction of State affiliations, such as, Survey Commissioners names, White's title, and the Survey name.

Map Showing Occurrence of Coal, Oil and Gas in West Virginia. By Israel Charles White, Ray Vernon Hennen, and Walter Lohring Webb; 1:500,000 scale; January 1, 1904

This is the first map to use contour lines, as White explained in a block of text on the map.

"The brown contour lines begin with 2000 feet above the sea, and show the 3000 and 4000 foot contours, thus indicating the mountain ranges and more elevated portions of the state in a much more accurate manner than the usual map symbols [hachures] for such features in the topography. This map of West Virginia, marks a distinct advance in the elimination of many glaring errors on the topographic base of the same that were unavoidably present in all former editions, since much of the area covered has been reduced by pantograph from the sheets of the U. S. Geological Survey."

The anticlinal axes have been removed so that their locations would not be misleading, and the oil and gas wells are now shown in red. Approximately 510 coal mines are shown as black, numbered dots with corresponding numbers for the mine names of each county listed in the left and right margins. The addition of this coal information made it necessary to increase the map size to 33 X 44 inches, and many counties in surrounding states were eliminated from the base map, particularly in Ohio.

The "Explanations" include Coal Mines, Oil Pools, Natural Gas Areas, Pittsburg Coal Areas, Allegheny-Kanawha Coal Areas, New River-Pocahontas Coal Areas, and Railroads under Construction. The color patterns for the coal areas differ slightly from earlier versions of the map. There were 6,073 copies printed (2,040 rolled and 4,033 folded) at a cost of $796.70 and this edition sold for $0.50, as did the next. White shrewdly weaved his justification for conservatism with economic benefits as he explained the distribution of the Pittsburg coal.

"Many farmers have felt aggrieved that the area of *Pittsburg Coal* has not been shown upon the map as extending farther westward, but in this matter it is better to err on the side of conservatism than to incur any danger of misleading the investing public, since if this coal really is present where the map would make it appear to be absent, the farmer who has not sold his coal will still own the same, and he will finally secure a much better price for it after the diamond drill has demonstrated its presence beyond question."

Map of West Virginia Showing Coal, Oil, Gas and Limestone Areas. By Israel Charles White and Ray Vernon Hennen; 1:443,520 scale; August 31, 1908

This is the first of two editions to use a scale of one inch equal to seven miles. The contour lines were maintained and a 15-minute grid replaced the 30-minutes of latitude and longitude. Other modifications included restoring the anticlinal axes and their names in red, eliminating railroads in the explanation, and delineating limestone areas in blue. White notes on the map: "The approximate areas of the principal Limestone belts of the State are added to this map in response to a general demand from

vey, v. 2, 725 p.

White, I.C., 1904, Petroleum and natural gas, precise levels: West Virginia Geological and Economic Survey, v.1A, 625 p.

White, I.C., 1908, Supplementary coal report: West Virginia Geological and Economic Survey, v. 2A, 720 p.

White, I.C., 1910, Report of the State Geological and Economic Survey for the fiscal years of 1909-1910: Charleston, 36 p.

White, I.C., 1921, List of coal mines in West Virginia July 1, 1921: West Virginia Geological and Economic Survey, 26 p.